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SEASON AND TIME ELEMENTS IN SAND-PLAIN FORMATION

THE SEASON ELEMENT

THE term sand-plain is here used in the generally accepted sense, that is, to designate the sand delta formed at the mouth of a glacial stream as it issued from the ice margin into the standing waters of a glacial lake or into the sea. The bulk of such a plain is made up of a succession of layers of fine material sloping at an angle of 15° or more in the direction in which the current is moving, or away from the head of the plain. Upon these layers, which are known as fore-sets, rests a comparatively thin and nearly horizontal layer of coarse material known as top-sets. A third class of layers is represented by the horizontally stratified clay beds deposited in front of the constantly advancing fore-sets, and partly overlain by them in consequence of this advance. In addition there is sometimes a fourth, but much less extensive series of layers which have slopes just the reverse of those of the fore-sets. They are known as back-sets, and are formed, sometimes by the upward movement of the water as it leaves the ice and passes up and over the sand-plain,[1] and sometimes by the settling of the margin of the plain in consequence of the melting of the ice upon which it may have partially rested.

Wherever sand-plains have been exposed it has been found that the development of back-sets is insignificant, seldom amounting to more than twenty or thirty feet even in the largest plains. It is evident that if the margin of the ice were retreating during the construction of a sand-plain, the formation of back-sets by the first method would at once become a prominent feature of the deposition. It is doubtful if back-sets of this type have ever actually been noted, and back-sets of any sort are, as we have seen, of rare occurrence and slight development. This

[1] Bull. Geol. Soc. Am., Vol. I, 197.

shows conclusively that the forward growth of the delta must have been extremely rapid, for an ice margin bathed constantly by the waters of the sea or a glacial lake could not long remain stationary. That the time of growth was a short one was early urged by Davis and is generally admitted by those familiar with such deposits. Even in the case of many of the larger plains it seems clear that the time of growth should be measured by months rather than by years, and the assumption that they are the result of a single season's stream work is not unwarranted.

If this view is accepted, the question at once arises as to whether the plain represents the deposits of the whole, or only a part of the season of ablation. The first thought would naturally be that they represent the whole, but on more careful consideration this seems less probable. The observations upon sand-plains show that there was practically no backward melting of the ice during their formation. The retreat, then, must have taken place under conditions more favorable to the melting or breaking up of the margin of the ice sheet than those existing during the formation of the plains, and to maintain that the sand-plains represent the whole of the summer periods of melting would mean the reference of the periods of retreat to the winter season, a conclusion not in harmony with the laws of nature.

As an alternative, it might be considered that the sand-plains represent summers of only moderate warmth, while the periods of melting were characteristic of seasons of a considerably higher average temperature. The melting of the ice, the discharge of the glacial streams, and the amount of detritus, would all have been increased under such conditions. In reality we find that often only a slight deposition of sediments took place between the stages of sand-plain growth, especially when plains are but short distances apart, as in the case of the Barrington and Nyatt Point sand-plains, hereafter to be described. Here the intermediate area is practically free from deposits of an inter-sand-plain period, indicating that the retreat of the margin took place during a period when little detritus was being set free from the ice by ablation.

A consideration of the conditions obtaining during the closing stages of the ice sheet leads to the conclusion that the periods or steps of the retreat in the vicinity of the Barrington Plain were characteristic of spring, corresponding more or less roughly to the present months of March, April and May.

Following is a summary of the reasons: (1) The insignificant development, or complete absence of back-sets in the most typical sand-plains, show that the retreat was not characteristic of the summer period. (2) The fall represents a waning, and the winter a cessation of all the conditions that can in any way be regarded as favorable to the ice retreat. The retreat cannot, therefore, be regarded as characteristic of these periods. (3) Though the actual precipitation may have been no greater than in the winter months, precipitation in the form of rain probably reached its maximum in the latitude of northern United States during the months of early spring. It is well known that water attacks ice much more rapidly than air at the same, or even higher temperatures. The period of spring rains must, then, have been one of rapid ablation. (4) The precipitation of the winter months must have been mainly in the form of snow, which according to Upham, would reach a maximum within a comparatively short distance of the margin. Under the influence of the spring rains the deep snow must have rapidly melted, helping swell the glacial, and especially the superglacial streams to sizable turrents. The rapidity with which such superglacial streams cut into the ice is well shown by some of the superglacial streams of Greenland, which, though usually short and of small size, have often sunk to some considerable depth into the ice. Such streams near the margin of the waning ice sheet would have rapidly cut through the ice to the very bottom, leaving detached pieces of various sizes and shapes which, however, would melt with comparative rapidity. (5) The streams during the spring, being fed mainly from the melting snow or direct precipitation, would carry a proportionally small amount of sediment, and the detritus instead of being deposited at a single point, as in the case of the sand-plains, would be distributed over a large area as an inconspicuous sheet. (6) In the summer the ice margin would become stationary and the deposition of the detritus, which was derived almost entirely from the ablation of the débris-laden ice, would be concentrated at definite points.

Although from the above considerations it seems reasonable to refer the shorter ice retreats between sand-plain stages to the spring months, it is probable that the longer retreats represent longer periods, perhaps in some cases years in length. In this case the absence of inter-sand-plain deposits may be more seeming than real, because of the sheet form of such deposits.

TIME ELEMENT

If the months of December, January, and February are eliminated, as there can be no doubt they should be, from the time of sand-plain growth, the retreat of the ice and the deposition of the plain must have taken place in the remaining nine months. The distance between sand-plain stages varied from a fraction of one up to several miles, and three months certainly seem none too long a time for such a retreat. If this be so, the sand-plains, or at least those of modern size, must have been formed in the six months still remaining.

A study of the conditions now existing in the larger glaciers of Alaska, showed at once that such a rate of deposition was by no means improbable. A calculation based on such conditions could not fail to be of interest, and would give valuable indication as to the probability of the general estimates. The results showed an unexpected and surprisingly close agreement with the estimates.

Basis of calculations.—Evidence as to the time of formation of sand-plains is afforded; (1) by the bulk of the sand-plain itself, and (2) by the bulk of the accompanying clays, which from their mode of formation, are known to be simultaneous in development and coextensive as to time. The time estimate is obtained by dividing the bulk by the daily discharge of sediment of the glacial stream. To find this discharge of sediment it is necessary to know the area of the cross-section of the stream, the velocity of its flow, and the percentage of sediment carried. The first two values are indicated by the esker and the material of which it is composed. The latter must be estimated from observations upon glacial streams existing under similar

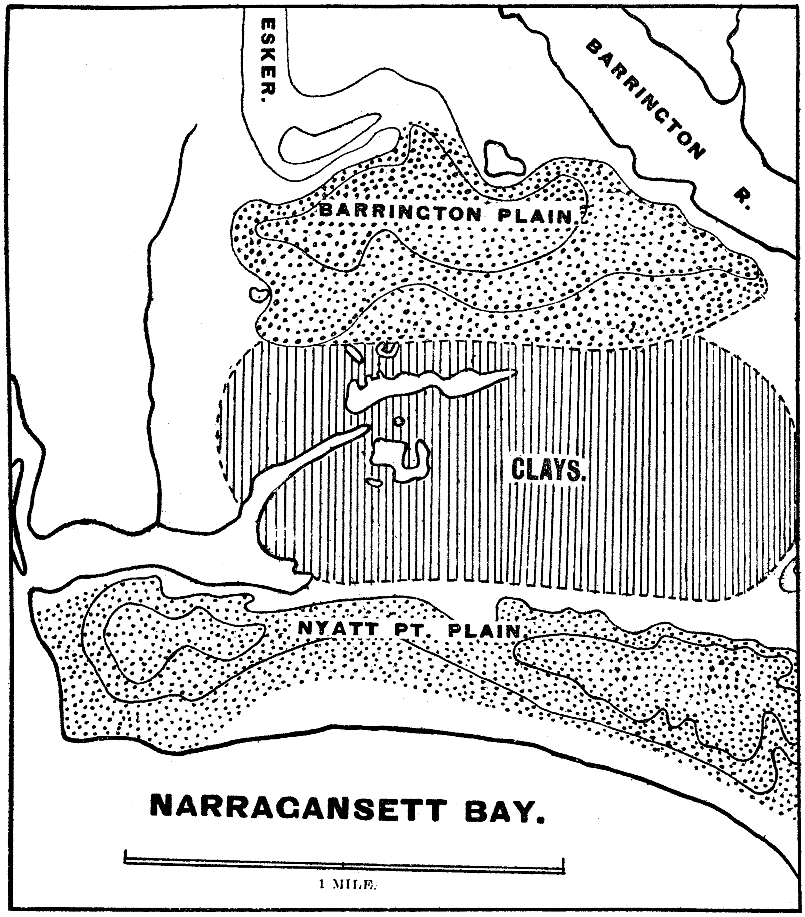

FIG. 1.—Map of Glacial Deposits, Barrington, R. I.[1]
Contour interval, 20 feet.

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[1] The geology is taken from map given by Mr. J. B. Woodworth in Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, Pl. LXII.

conditions at the present time. Such observations have been made by Wright, Reid, and others in regard to the fine sediments such as make up the so-called glacial clays, and it is upon these observations that the present estimates are based.

Locality selected. — Conditions favorable to a calculation of the time of formation from the extent of the plains, or their associated clays, are in almost every case wanting. In 1896, however, Woodworth described[1] and mapped a series of unusually typical deposits in the town of Barrington, R. I. A visit to the locality showed the conditions to be almost ideal, and admitting of calculations of some definiteness. The clays were selected as a basis of calculation in preference to the sand-plain itself, because of the greater number and reliability of the Alaskan observations upon this class of sediments.

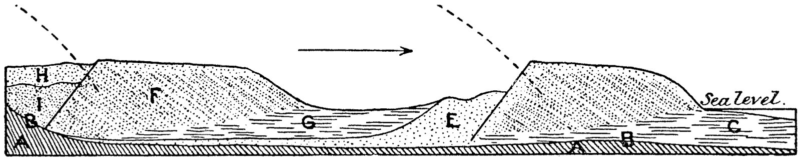

FIG. 2.—Section across Barrington, R. I., showing relations of clays to sand-plains. A, Terrane of Carboniferous age; B, Glacial drift older than Nayatt Point stage; C, Clays contemporaneous with the Nayatt Point sand-plain; E, Gravel and sands deposited upon the melting of the ice along the head of the Nayatt Point plain; F, Barrington sand-plain; G, Barrington clays; H, esker; I, gravel and sands laid down upon the melting of the ice back of the Barrington plain. — J. B. WOODWORTH: *Seventeenth Annual Report U. S. Geol. Surv., Part I, p. 987.*

Barrington clays.—These clays are exposed at the surface over an area of about six tenths of a square mile (Fig. 1). On the south the clays rest against the ice-contact slope of the Nyatt Point sand-plain, while on the north they extend as a gradually thinning wedge beneath the Barrington plain, reaching their northern limit approximately along the ice-contact slope of this latter plain (Fig. 2). The depth of the clays in the vicinity of the railroad, as shown by borings, is about sixty feet. With the exception of one slight break there is a ridge, partly till and

Seventeenth Annual Report U. S. Geol. Surv., Part I, 987, 988; and Am. Geol., VOL. XVIII, 161–164, 391, 392.

partly of modified material, connecting the two sand-plains on the east, and having an average height of about forty feet. On the west there is no marked rise between the clays and the waters of the bay, the latter even at the present time having access to the clays by a fair-sized estuary. The surface of the clays is practically at sea level.

The clays, which vary from gray to blue-gray in color, are composed principally of quartz flour—the ultimate product of glacial scouring—with a comparatively slight intermixture of true clay. Their amount, allowing for the thinning out in various directions, and taking their specific gravity as 2.5, is found to be approximately 95.3 million tons.

Conditions at time of deposition.—The heights of the two sand-plains are about fifty feet and indicate a probable height of water at the time of their formation of at least forty feet above the present sea level. The ice on the north, the ridge on the east, and the Nyatt Point plain on the south would form an inclosed bay, with practically no opening except at the west. Here, however, there must have been an opening something like three fourths of a mile wide and thirty-five to forty feet deep connecting with the sea and allowing a more or less complete commingling of the salt and fresh waters.

Into this inclosed bay emptied, as indicated by its esker, a glacial stream 150 feet wide, with a probable depth of some twenty feet, and a velocity sufficient at times to move pebbles up to six inches in diameter. This would indicate a maximum velocity of a little over six feet per second, but the average material composing the esker would require a current certainly not over five feet per second. The discharge of such a stream would be 15,000 cubic feet per second.

The area of the cross-section of the outlet from the inclosed bay was about 138,000 square feet, or some forty-six times that of the glacial stream. If discharge took place uniformly through the outlet the velocity would have been one and one third inches per second. If the flow of the fresh water took place as a surface current, as would have been the tendency, a somewhat greater velocity would have resulted, but not enough greater to have prevented the settling of the sediment. The ebb and flow of the tide, which is about four feet, would have decreased the outflow some 25 per cent. during flood tide, and increased it by a corresponding amount during the ebb.

The average distance through which the water would move in its passage from the mouth of the glacial stream to the outlet would be at least a mile. The current, which at the frontal slope of the sand-plain had a velocity, as indicated by the material deposited, of some eight inches per second, would decrease until certainly not over three inches per second at the outlet. Its passage would require fully four hours.

Sediment of glacial streams.—According to Helland,[1] as quoted by Reid,[2] the maximum sediment values of their respective regions are represented by the Unteraar glacier of Switzerland, which carries .142 grams per liter; the Langedal glacier of Norway, carrying .513 grams; and Alangordleck glacier of Greenland, carrying 2.37 grams. Both Wright and Reid found much more sediment in the waters from the Muir glacier of Alaska, the former recording a load which reduces to 12.12 grams per liter,[3] and the latter a load as high as 12.98 grams per liter.[4] As the Alaskan glaciers most nearly represent the conditions obtaining during the closing stages of the continental ice sheet, I have taken Reid's value of 13 grams (actual value, 12.98 grams) as a basis in calculating the time of formation of the Barrington clays.

In all probability the sediment discharged by the streams draining the continental ice sheet was even greater than that of the most heavily loaded glacial streams of today. I have sought to neutralize this difference as much as possible by applying as a mean value to the Barrington deposits the maximum value of the Muir glacier sediments.

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[1] HEIM's Gletscherkunde, p. 363.

[2] Sixteenth Annual Report, U. S. Geol. Surv., Pt. I, p. 457.

[3] Ice Age in North America, p. 64.

[4] *Loc. cit.*, p. 454.

Rate of settling.—Recently, in connection with professional work for the Metropolitan Water Board of Massachusetts, Professor W. O. Crosby has incidentally had occasion to determine the rate of settling of the finer portions (*i. e.*, quartz-flour) of both the till and the stratified drift. No definite maximum limit has ever been fixed for the grains of quartz flour, but in the experiments in question this name was applied to that portion passing through a sieve of 170 meshes to an inch. The larger grains are about $\frac{1}{300}$ of an inch in diameter.

In the experiments, the results of which Professor Crosby has kindly placed at my disposal, 5 grams of the quartz flour were introduced at the top of a half-inch tube containing five feet of water. The time of settling was then taken. The results showed that fully 75 per cent. of the material settled within thirty minutes from the time of insertion, and in the majority of cases none whatever remained in suspension at the end of sixty minutes. In other cases a distinct turbidity, probably due to true clay, was still noticeable at the end of this time. This was determined by filtering and weighing, the amount varying from a mere trace up to 10 per cent.

The results show that even in fresh water the settling of quartz flour is very rapid, the greater part settling at a rate of at least ten feet per hour. In the inclosed bay in which the Barrington clays were deposited the water was salt, or at least decidedly brackish, and the rate of settling must have been much increased, especially in the case of the finer material, which, according to W. H. Brewer, will settle as much in salt water in thirty minutes as it would in as many months in perfectly pure water.[1] There can be no reasonable doubt, then, that practically the entire amount of sediment brought in by the glacial stream was deposited within the inclosed bay.

Statement of problem and results.—During a certain stage of the ice retreat from the region of Narragansett Bay, the area now covered by the Barrington clays stood at a level some forty feet below that at present existing, and was covered by a body of salt or brackish water which rested against the ice on the north, and was practically cut off from the sea on the east by a till ridge, and on the south by the Nyatt Point sand-plain. Into this body poured a glacial stream with a volume of some 15,000 cubic feet per second, and bearing a load which I have assumed as a maximum to be 13 grams per liter, amounting to 526,500 tons per day. From experiment it has been found that material like that of the Barrington clays settles very rapidly, indicating that practically the whole amount brought in by the glacial stream must have been deposited within the inclosed area indicated.

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[1] Am. J. Sci., III, 29, p. 4.

The amount of the clay is some 95.3 million tons. Dividing this by the daily discharge of sediment of the glacial stream, *the time of the deposition of the clays is found to be 181 days*, or almost exactly six months.

General application. — Though in the sand-plains of different localities, the proportion of sand and clay varies greatly, the Barrington deposits taken as a whole probably represent very nearly the average conditions. I am satisfied, therefore, that the results obtained in the case of the Barrington plain, though strictly speaking they are applicable only to this plain, represent fairly closely the time required for the formation of the *average* sand-plain. If, for the reasons given on a previous page (p. 454), the ice retreat is considered as taking place in the early spring, it would follow that these figures represent a maximum, rather than a minimum, time limit. In the case of large plains, however, with areas of several or many square miles it may be possible to consider the period of deposition as extending over more than one season of melting, there being in the meantime either no retreat of the ice margin, or a retreat so slight that the intervening space was completely filled, and the sand-plains united into a single compound plain.

Remarks. — One of the points most strongly emphasized by the results obtained, is the almost incredible amount of sediment discharged by the Barrington glacial stream during the few months of summer activity. The daily discharge of sediment by this small stream, not over 150 feet in width, was equivalent to 40 per cent. of that of the Mississippi.[1]

The small amounts of the coarse material, compared with the amount of clay, is also a significant feature. It shows fully two thirds of the detritus brought in by the stream was of the finely comminuted quartz flour. The velocity was such that had the current come in contact with the subglacial till to any extent the percentage of coarse material would have been much greater. Its absence indicates, therefore, that practically the entire amount must have been derived from the ablation of the ice. The high percentage of the finer débris contained within the ice is certainly a striking feature.

MYRON L. FULLER.

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[1] J. B. WOODWORTH, *loc. cit.*, 162.